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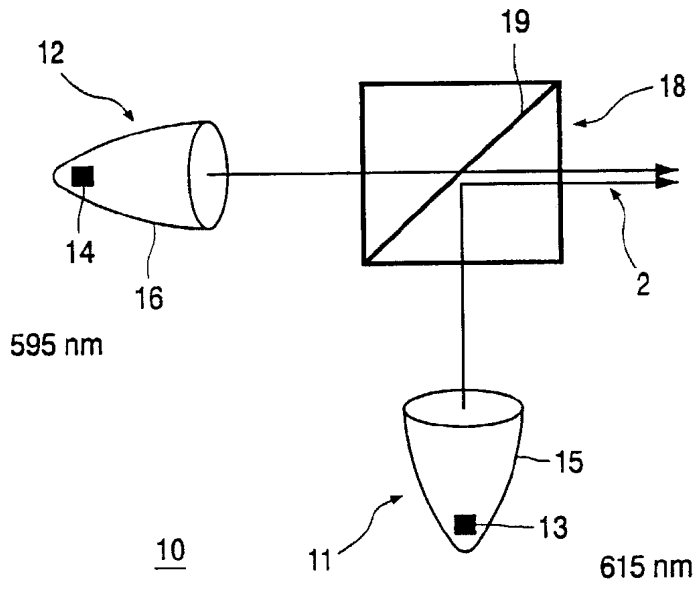
(54) Title: DISPLAY SYSTEMS INCORPORATING LIGHT-EMITTING DIODE LIGHT SOURCE



(57) Abstract: A display system has a light source which is composed of at least two LED sources having slightly different peak wavelengths of light emission. The separate LED sources are combined into a single beam having increased lumen output with little or no increase in etendue. Such combined sources of different colors (eg., red, green and blue) are useful as the light engine in display systems having a limited etendue, arising for example from the use of small light modulator panels.

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Display systems incorporating light-emitting diode light source

BACKGROUND OF THE INVENTION

This invention relates to display systems, and more particularly relates to display systems incorporating light-emitting diode (LED) light sources employing a combination of LEDs of different wavelengths.

The increasing availability of LEDs of various colors (eg., red, green and blue) and increasing lumen output has created interest in producing commercial products for lighting and display applications.

It has been suggested, for example, to combine red, green and blue-emitting LEDs to produce a white light source for general illumination purposes. See U.S. patent 5,851,063.

It has also been suggested to use red, green and blue-emitting LEDs as the light sources in a direct view miniature display for mounting on a helmet or a pair of eyeglasses, operating with a single light modulator panel in the frame-sequential mode. See U.S. patent 5,808,800. LEDs are attractive for such applications due to their relatively small size, low power consumption and their ability to switch on and off at a frame rate sufficiently fast to cause the viewer to integrate the separate color images into a full color image.

These same features make LEDs attractive for other applications. In particular, the small size of LEDs makes them attractive for use in systems having a limited etendue, such as projection systems employing one or more small liquid crystal light modulator panels.

However, despite the progress which has been made in increasing the lumen output of LEDs, at the present stage of development, individual LEDs still provide less than desired lumen output for some applications. Some increases in lumen output are possible by combining several individual LEDs into arrays or clusters, but are still less than desired, particularly for projection display systems, and further increases are limited by the etendue of the systems.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide a display system employing an LED-based light source of increased lumen output.

This object is achieved by the display system according to the invention as defined in claim 1.

The invention is based on the realization that individual LEDs have output beams characterized by relatively narrow spectra (eg., about 20 nm) and can be produced to have any desired peak wavelength within a wide range, and that the output beams of LEDs of different but closely spaced peak wavelengths (spacing of 1 nm or more) can be combined into a beam of greater lumen output with little or no increase in etendue. Herein, a combination of two or more of such LEDs is referred to as an "LED set".

Further advantageous embodiments are defined in the dependent claims.

In accordance with the invention, there is provided a light source for a display system comprising at least one LED set, and also comprising means such as a dichroic filter to combine the separate output beams from the individual LEDs of the set into a beam of greater lumen output with little or no increase in etendue.

It is an advantage of the display in accordance with the invention lumen output vs increased without increasing the lumen output of the individual LEDs of the light source.

The separate output beams may be produced either by individual LEDs or by clusters or arrays of LEDs having approximately the same peak wavelength of emission. Herein, these individual LEDs, LED clusters and arrays will be referred to collectively as "LED beam sources" or "LED sources".

In one embodiment of a display system light source of the invention, the LED set is combined with one or more LED beam sources and/or LED sets of different colors to produce a combined light output dependent on the wavelengths of the component colors. Control circuitry may be provided to change the power levels of the colors and/or to switch the colors on and off periodically, in order to vary the color and/or brightness of the display.

In accordance with a preferred embodiment of the invention, there is provided a display system incorporating such a light source, comprising separate primary color channels of red, green and blue beams, one or more of which color channels is produced by an LED set, are modulated by one or more light modulator panels to produce a color display.

The different peak wavelengths in each LED set should be separated from one another by at least 1 nm, and preferably by about 20nm, with greater separations being determined by desired spectral characteristics of the combined beams.

For example, the green channel could be composed of a set of two LED beam sources, one source composed of one or more 530 ± 10 nm LEDs and the other source composed of one or more 550 ± 10 nm LEDs. The red channel could be composed for example, of a 595 ± 10 nm source and a 615 ± 10 nm source, while the blue channel could be composed for example, of a 450 ± 10 nm source and a 470 ± 10 nm source.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an LED set of the invention, showing dichroic mixing of two red LED source beams into a single red beam;

Fig. 2 is a diagram of an LED source comprising a cluster of individual LEDs;

Fig. 3 is a diagram of a light source of the invention including a green LED set; and

Fig. 4 is a diagram of a color projection display system incorporating a light source of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Fig. 1, there is shown one embodiment of an LED set 10 including two LED sources 11 and 12, and a dichroic mixing arrangement in accordance with the invention. Red LED sources 11 and 12 each comprise a single LED 13,14 located within a reflector 15,16 and emitting a source beam at a different peak wavelength, 595 and 615 nm, respectively. The source beams are each directed at an incident angle of 45 degrees onto opposite sides of dichroic filter 19, supported within optical element 18. Filter 19 is designed to transmit the 595 nm beam and to reflect the 615 nm beam. The transmitted beam and the reflected beam emerge from optical element 18 along a common path as a combined beam 2 of increased lumen output but unchanged etendue.

LED sources 11 and 12 could alternately each comprise a cluster or array of individual LEDs, as shown schematically in Fig. 2. LED source 20 includes an array of individual LED packages 23. Each package includes an LED 22 carried on a substrate 24, encapsulated in a dome-shaped element 26, and fitted into lens 28. Collector lens 30 directs light from the array to a target 32, such as an electro-optic light modulator panel.

The combined beam may be employed as a standard single color beam of broader spectrum, and can be subsequently mixed or combined with other color beams for display purposes.

For example, in the case in which red, blue and green channels of fixed etendue are combined to produce white light, the present state of LED technology does not allow the production of a green LED of sufficient lumen output, so that the full lumen output of the red and blue LEDs, which are more closely balanced, cannot be utilized without upsetting the desired color balance. By combining two green LED sources of different but closely spaced peak wavelengths eg., 530 nm and 550 nm, the lumen output of the green beam is nearly doubled, allowing the red and blue beams to be driven to higher lumen outputes also, resulting in a near doubling of the combined white light output.

Such a light source is shown diagrammatically in Fig. 3, in which green LED sources L1 and L2, having beams G1 and G2, whose peak wavelengths are 530 $\pm$ 10 and 550 $\pm$ 10 nm, respectively, combined into a single beam by dichroic mirror M1. This combined green beam is then combined with a red beam R from LED source L3 by dichroic mirror M2. The combined red and green beams are then combined with blue beam B from source L4 by dichroic mirror M3, to produce a white light output beam W.

An exemplary three-panel color projection display system of the invention is shown diagrammatically in Fig. 4. Green beams G1 and G2 from sources L1 and L2, respectively, are combined into a single beam by dichroic mirror M1. Similarly, red beams R1 and R2 from sources L3 and L4 are combined by mirror M2. The green and red beams are then directed along a common axis by dichroic mirror M3 to light modulator panel P and thence to projection lens PL. Blue beams B1 and B2 from sources L5 and L6 are combined by dichroic mirror M4, and then directed along the common axis of the red and green beams by dichroic mirror M5. The red, green and blue beams are modulated separately by light modulator panel P in accordance with separate display signals. For example, in the known frame sequential driving scheme for reproducing a color video signal, the panel P is addressed with the separate primary color components of the video signal at the video frame rate eg., 60 Hz, and the LED sources L1 through L6 are synchronously pulsed on and off in a manner to illuminate panel P with the color corresponding to that of the primary color component being addressed. Panel P is preferably a liquid crystal display device.

The actual order of the dichroic mirrors need not be that shown. The invention allows the beams to be mixed in any sequence consistent with good filter and optical path design criteria.

The invention has been described in terms of a limited number of embodiments. Other embodiments, variations of embodiments and art-recognized equivalents

will become apparent to those skilled in the art, and are intended to be encompassed within the scope of the invention, as set forth in the appended claims.

CLAIMS:

1. A display system comprising:

a light source comprising at least one LED set (10), the LED set (10) comprising at least two LED sources (9,11), each LED source (11,12) having an output beam with a peak wavelength which is different from but closely-spaced to the peak wavelength of the other LED source (12,11) of the LED set (10), the light source also comprising means (18) for combining the separate output beams into a single beam; and

at least one control means (39) for controlling light from the light source in accordance with a display signal.

2. The display system of claim 1, in which the LED set (34) is combined with one or more LED sources (36,38) and/or one or more LED sets (42,44) of different colors to produce a combined light output dependent on the wavelengths of the component colors.

3. The display system of claim 2, in which the control means (39) includes means (48) for independently controlling the input power to the respective colors, thereby to vary the color and/or brightness of the display.

4. The display system of claim 2, in which the LED set (34) is a green LED set, and is combined with a red LED source (36) and a blue LED source (38) to produce a display.

5. The display system of claim 2, in which the green LED set (40) is combined with a red LED set (42) and a blue LED set (44).

6. The display system of claim 1, in which the LED sources in an LED set are combined by dichroic filtering means (M1, M2, M3).

7. The display system of claim 1 in which the control means (39) comprises at least one light modulator panel (P).

8. The display system of claim 7 in which the light modulator panel (P) comprises a liquid crystal display device.

9. The display system of claim 7 in which the light source comprises three separate LED sets (40,42,44) forming primary color channels of red, green and blue beams, respectively, each channel modulated by one or more light modulator panels (P) to produce a color display.

10. The display system of claim 9, in which each LED set (40,42,44) consists of two LED sources (L1,L2,L3,L4,L5,L6), the green channel LED sources (L1,L2) having peak wavelengths of about 530 $\pm$ 10 nm and 550 $\pm$ 10 nm, respectively; the red channel LED sources (L3,L4) having peak wavelengths of about 595 $\pm$ 10 and 615 $\pm$ 10 nm, respectively; and the blue channel LED sources (L5,L6) having peak wavelengths of about 450 $\pm$ 10 and 470 $\pm$ 10 nm, respectively.

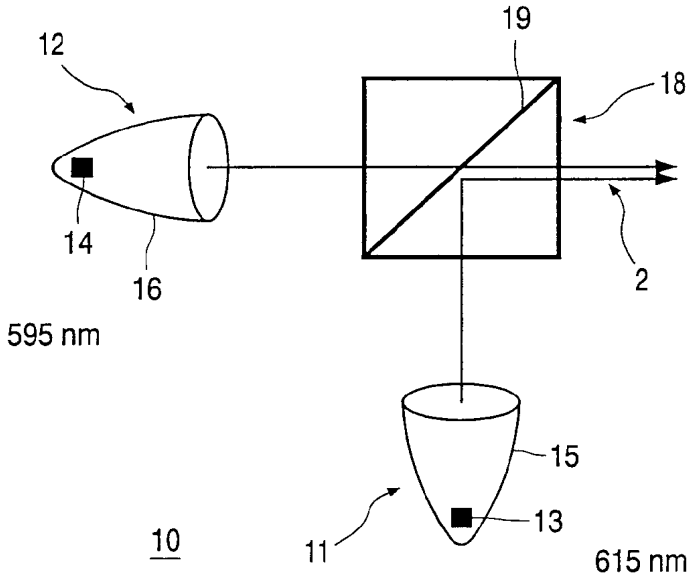

FIG. 1

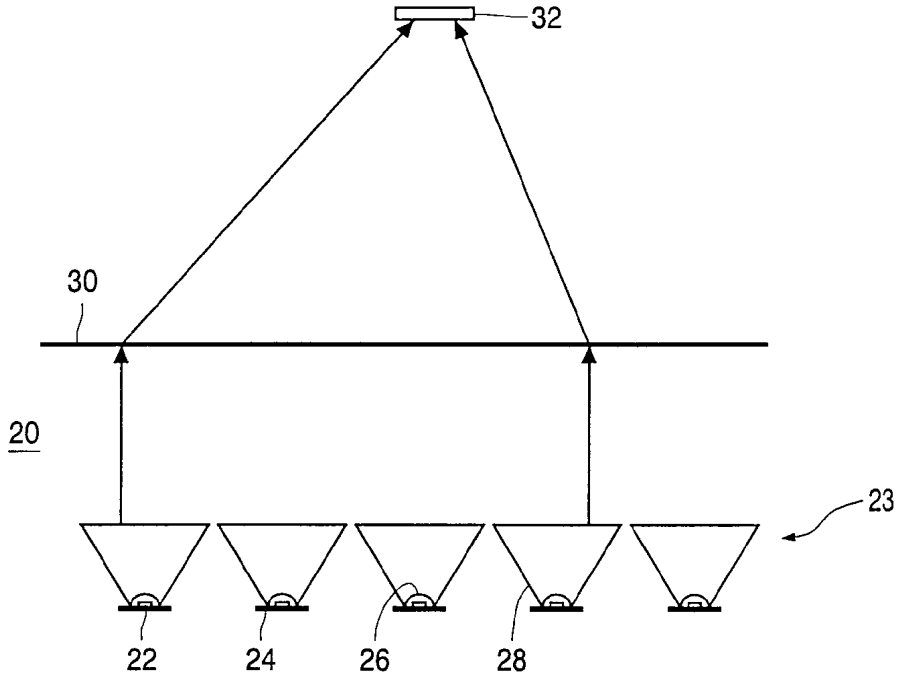

FIG. 2

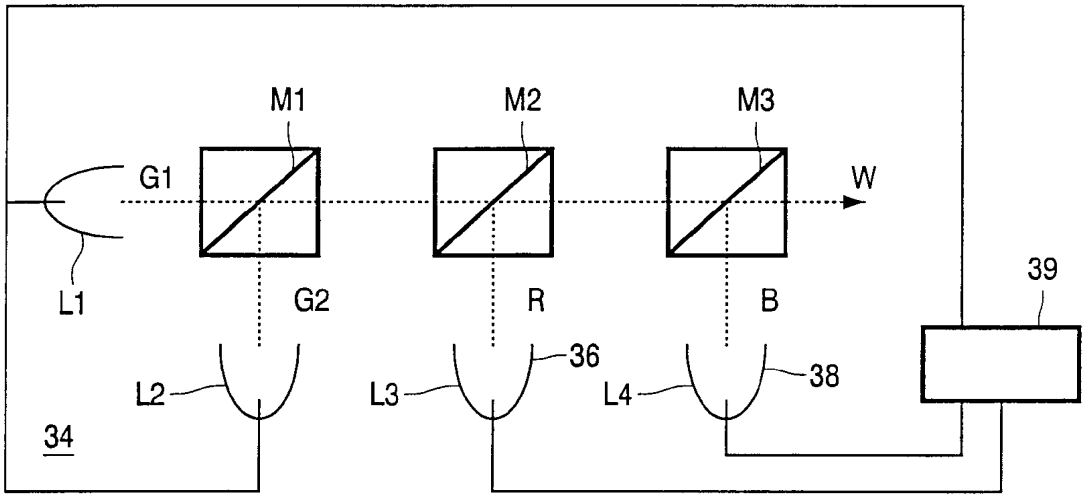
M1
M2
M3
G1
W
L1
G2
R
B
39
36
L2
L3
L4
38
34

FIG. 3

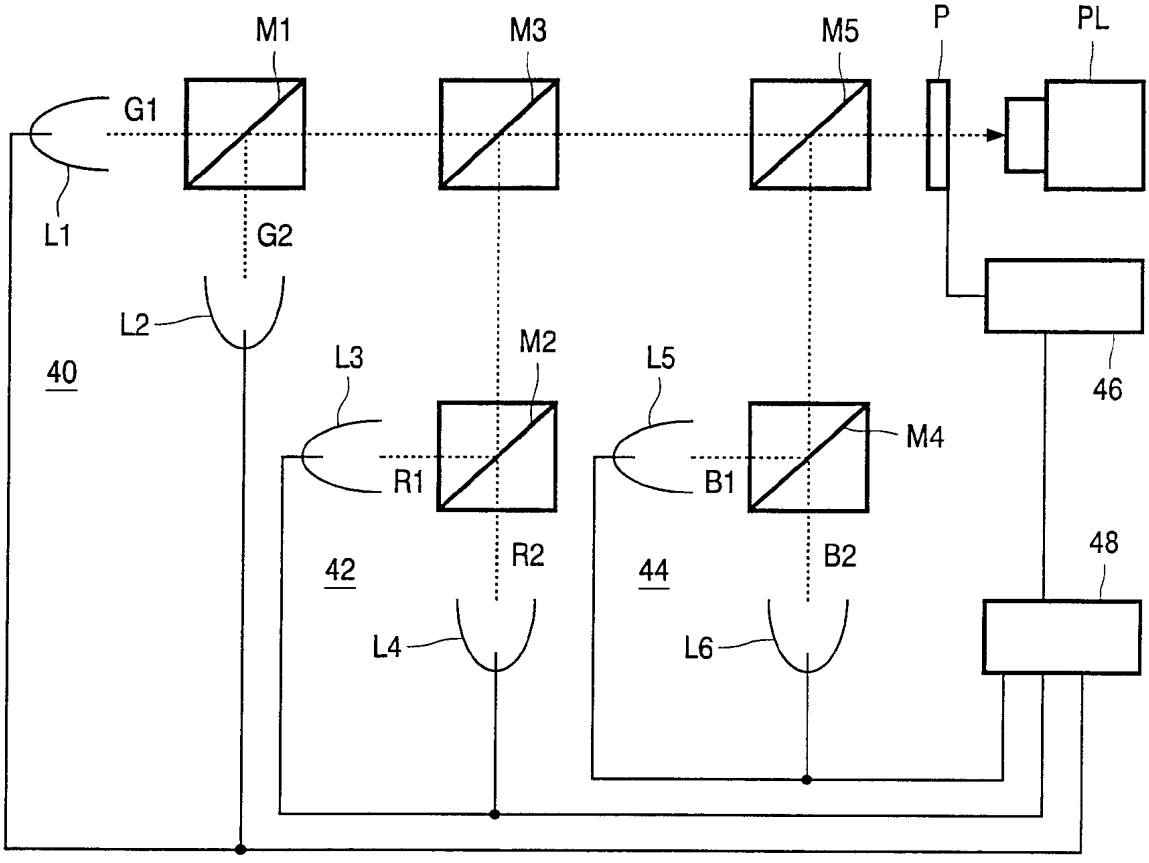
M1
M3
M5
P
PL
G1
L1
G2
L2
40
L3
M2
L5
M4
R1
B1
46
42
R2
44
B2
48
L4
L6

FIG. 4

INTERNATIONAL SEARCH REPORT

In. ational Application No
PCT/EP 00/11651

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G09G3/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G09G G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 20811 A (SDL INC) 3 August 1995 (1995-08-03) page 6, line 7 -page 7, line 16; figure 1 page 10, line 15 -page 11, line 35 page 21, line 17 - line 31; figure 15A -----	1-9

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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Date of the actual completion of the international search	Date of mailing of the international search report
15 March 2001	22/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Amian, D

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

In ational Application No
PCT/EP 00/11651

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9520811 A	03-08-1995	EP 0742940 A	20-11-1996
		JP 9508476 T	26-08-1997